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JPRS: 6465

22 December 1960

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JPRS: 6465

CSO: 4718-D

PREDICTING THE HEIGHT OF THE 700-MB ISOBARIC SURFACE BY MEANS OF THE "URAL" ELECTRONIC COMPUTER

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/Following is a translation of an article by V. I. Gubin and S. Karimberdyyeva in the Russian-language periodical Izvestiya Akademii nauk UzSSR. Seriya fiziko-matematicheskikh nauk (Bulletin of the Academy of Sciences Uzbek SSR. Physicomathematical Science Series), Tashkent, No. 3, 1960, pages 38-43./

In connection with the present development of computer technology there are great potentialities for numerical prediction of the weather and, in particular, for the prediction of the synoptic situation. We shall examine one of the systems of the precalculation of the geopotential height of the 700-mb isobaric surface by means of the "Ural" electric computer, which is being used in the calculation center of the Institute of Mathematics of the Academy of Sciences Uzbek SSR.

Basic Ratios

For the calculation of the geopotential height of the 700-mb isobaric surface we used a barotropic model of the atmosphere. Although in this system a change of the height of the isobaric surface is determined only by the transfer of the vortex, it is nevertheless interesting to explain the effect of the steric and time spacings upon the quality of the prediction, namely, on this simplest model. The original equation in the one-layer problem is

$$\triangle \phi = - (\phi, \frac{\Delta \phi}{1} + 1), \qquad (1)$$

where ϕ is the geopotential,
1 is the Kariolis parameter,
$\phi = \frac{d\phi}{dt}$,

$$\triangle = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} \text{ - Laplacian.}$$

Inasmuch as $\phi = gH$ ($g = 9.8$ m/sec^2, H being the height of the isobaric surface), then equation (1) may be rewritten in the following form

$$\Delta \dot{H} = -\left(H,\ g\,\frac{\Delta H}{l} + l\right). \tag{2}$$

We shall solve this equation by the terminal differences method. For the solution we chose a grid field with a spacing δs = 250 km, the number of points being equal to 391 (where x is 23 points and y, 17). Equation (2) is solved in the condition of the rotation of H to zero on the boundary of the grid field. Let us introduce the symbol

$$\theta = \left(H,\ g\,\frac{\Delta H}{l} + l\right). \tag{3}$$

Then for the arbitrary unit with index i, j may be written

$$\theta_{ij} = \frac{g}{l}\,(H,\ \Delta H)_{ij} + (H,\ l)_{ij} = \frac{g}{l}\left(\frac{dH}{dx}\,\frac{d\Delta H}{dx} - \frac{dH}{dy}\,\frac{d\Delta H}{dx}\right)_{ij} + \frac{dH_{ij}}{dx}\,\frac{dl}{dy}\,. \tag{4}$$

Using centered differences, we shall obtain approximate values of the derivatives:

$$\frac{dH_{ij}}{dx} \approx \frac{H_{i+1,j} - H_{i-1,j}}{2\delta s};\quad \frac{dH_{ij}}{dy} \approx \frac{H_{i,j+1} - H_{i,j-1}}{2\delta s} \tag{5}$$

$$H_{ij} \approx \frac{H_{i+1,j} + H_{i,j+1} + H_{i-1,j} + H_{i,j-1} - 4H_{ij}}{\delta s^2}$$

$$\frac{d\Delta H_{ij}}{dx} \approx \frac{\Delta H_{i+1,j} - \Delta H_{i-1,j}}{2\delta s};\quad \frac{d\Delta H_{ij}}{dy} \approx \frac{\Delta H_{i,j+1} - \Delta H_{i,j-1}}{2\delta s}$$

The expression for θ, if (5) is taken into consideration, will take the following form:

$$\theta_{ij} = \frac{k_1}{\delta s^2}\,\big[(H_{i+j,j+1} - H_{i+1,j-1} + H_{i,j+2} - H_{i,j-2} + \tag{6}$$

$$H_{i-1,j+1} - H_{i-1,j-1}) \cdot (H_{i+1,j} - H_{i-1,j}) -$$

$$(H_{i+1,j+1} - H_{i-1,j+1} + H_{i+2,j} - H_{i-2,j} + H_{i+1,j} -$$

$$H_{i-1,j-1})(H_{i,j+1} - H_{i,j-1})] + \frac{k_2}{\delta s^2} \times (H_{i+1,j} - H_{i-1,j}).$$

Here

$$k_1 = \frac{g}{4l\delta s^2}, \quad k_2 = \frac{l_y \delta s}{2}.$$

If there is taken

$$l = 1.2 \cdot 10^{-4} \frac{1}{sec}; \; l_y = 1.92 \cdot 10^{-11} \frac{1}{meter\ second}; \; g = 9.8 \frac{meter}{sec};$$

$\delta s = 2.5 \cdot 10^5$ meter, then k_1 and k_2 will have the values

$$k_1 = 3.92 \cdot 10^{-6} \frac{1}{sec \cdot gpdkm}; \; k_2 = 2 \cdot 10^{-6} \frac{1}{sec}.$$

Let us introduce the symbol

$$\Theta'_{ij} = \Theta_{ij}\delta s^2.$$

Then from (2), representing the left side in a different form, we shall obtain for H_{ij}

$$\dot{H}_{ij} = \frac{\dot{H}_{i+1,j} + \mathring{H}_{i,j+1} + \dot{H}_{i-1,j} + \dot{H}_{i,j-1} + \Theta'_{ij}}{4}. \tag{7}$$

From the ratio (7) it is possible to find the values for $\dot{H}$ in all units, using the iteration process. However, the problem may be solved more quickly (in the sense of the use of machine time) without a decrease of accuracy, if a local system is used. For this we will consider that the effect of the second series of points (with respect to i, j) is insignificantly small, and the contribution of these sources of Θ' can be disregarded. Such an assumption is adequately substantiated by the presence of a more or less uniform distribution of positive and negative sources on this local form.

In our example of calculation, nine points were chosen as units, in which the effect of the sources was taken into consideration: point i, j, in which is being sought $\mathring{H}_{ij}$, and eight points, which surround it, -i+1,j; i,j+1; i-1,j; i,j-1; i+1,j+1; i-1,j+1; i-1,u-1; i+1,j-1. Then, setting up the nine equations [1], taking into consideration the conditions in the local contour, we shall write $\dot{H}_{ij}$ in the following form:

$$\dot{H}_{ij} = \frac{3}{8}\,\Theta'_{ij} + \frac{1}{8}\,(\Theta'_{i+1,j} + \Theta'_{i,j+1} + \Theta'_{i-1,j} + \Theta'_{i,j-1}) + \tag{8}$$

$$\frac{1}{16}\,(\Theta'_{i+1,j+1} + \Theta'_{i-1,j+1} + \Theta'_{i-1,j-1} + \Theta'_{i+1,j-1}).$$

We also used this expression for the determination of a change of the height of the isobaric surface in each unit of the grid field. Selecting the spacing by time Δt, it is possible to then determine the next field, using the Euler method,

$$H^{t+\Delta t}_{ij} = H^{t}_{ij} + H^{t}_{ij} \cdot \Delta t. \tag{9}$$

In the calculation of the height of the 700-mb surface we used Δt, equal to 1 hour, 1.5 hours, and 2 hours. After the field through Δt was found, the values of new H were substituted in (6) and the whole calculation procedure was repeated. Inasmuch as the prediction of the field was given for 24 hours, the number of spacings by time was equal to 24, 16, and 12.

In the calculation process errors are accumulated which can lead (as in any kind of differential system) to the appearance of spurious waves. In order to avoid these spurious waves, we carried out a smoothing of the field every 6 hours according to formula [2]

$$H_{sm} = \frac{5}{8}\,H_{ij} + \frac{1}{16}\,(H_{i+1,j} + H_{i,j+1} + H_{i-1,j} + H_{i,j-1}) + \tag{10}$$

$$\frac{1}{32}\,(H_{i+1,j+1} + H_{i-1,j+1} + H_{i-1,j-1} + H_{i+1,j-1}).$$

The ratios (6), (8), (9), and (10) are basic for the solution of the problem of the pre-calculation of the height of the 700-mb isobaric surface for 24 hours. We also investigated the effect of steric spacing upon the quality of the prediction. The steric spacing varied only with the calculation of the Laplacian from H, inasmuch as ΔH is the most sensitive to a change of δs (derivatives of a high order). The spacings $\delta s = 250$ and $\Delta s = 500$ km were tested. In the first case two series of extreme points were lost, and consequently $\mathring{H}$ was determined for 247 points; and in the second case, three series of points were lost, and $\mathring{H}$ was determined for 187 points.

Finally, let us note that through the smoothing of the field according to (10) there occurred a unique correction of the values of H in the external zone (excluding the external contour) of points, for which $\mathring{H}$ is not calculated. This fact can be considered as a certain correction of boundary conditions.

Calculation and Analysis of Results

The pre-calculation of the height of the 700-mb isobaric surface was carried out on the "Ural" electronic computer in the above-indicated sequence. The program was placed in two zones: the program was entered in the third zone and the original data in the fourth. A block diagram of the program is presented below /see Figure Appendix/. Selected for testing the efficiency of the prediction system was the period 14 through 18 November 1954, which is characterized by the intensive changeover of the planetary height frontal zone (PVFZ). To explain the potentialities of the barotropic model at various stages of the transformation of the PVFZ is of much interest. It turned out that for the given period the system "caught" best the development (beginning of the period) and "caught" worst the process of damping (the end of the period) with "erosion" of the PVFZ over ETS. For various time ($\triangle t$) and steric ($\triangle s$) spacings, the correlation coefficient between the calculated and actual variability of the heights ranges from 0.6 to 0.75. In addition to this, it was noted that the best coincidence in all the cases which were analyzed was observed for $\triangle s = 500$ km and $\triangle t = 1$ hour, and almost the very same thing for $\triangle t = 1.5$ hours. For the steric spacing $\triangle s = 250$ km, the correlation coefficient for all time spacings was at a minimum. This is apparently explained by the fact that in the selection of such a $\triangle s$, the defects of subjective analysis have a strong effect upon the results of the calculation. With the selection of a time spacing $\triangle t > 1.5$ hours, there appeared spurious waves (first of all in the east), which reduced the quality of the pre-calculated synoptic situation.

Examples of the coincidence of the calculated (solid lines) and the actual (broken lines) synoptic position are presented in Figure 1a ($\triangle s = 500$ km, $\triangle t = 1$ hour), 1b ($\triangle s = 500$ km, $\triangle t = 1.5$ hours), and 1c ($\triangle s = 250$ km, $\triangle t = 1$ hour). For the original map we selected AT-700 for 18 hours, 14 November 1954, according to which we calculated the map AT-700 for 18 hours, 15 November 1954 (i.e., the prediction for 24 hours). Comparison of the calculated and actual maps indicates that for $\triangle s = 500$ km and $\triangle t = 1$ hour the best coincidence occurs, and for $\triangle s = 250$ km and $\triangle t = 1$ hour the worst coincidence occurs. For the calculation of $\triangle H$ according to the map of the conventional (subjective) analysis, it is expedient to use steric spacing of the order of 500 km. For the determination of the future field by the Euler formula the time spacing $\triangle t$ should be included within the limits $1 < \triangle t < 2$. It stands to reason that the selection of the time spacing essentially depends upon the character of the process which is occurring.

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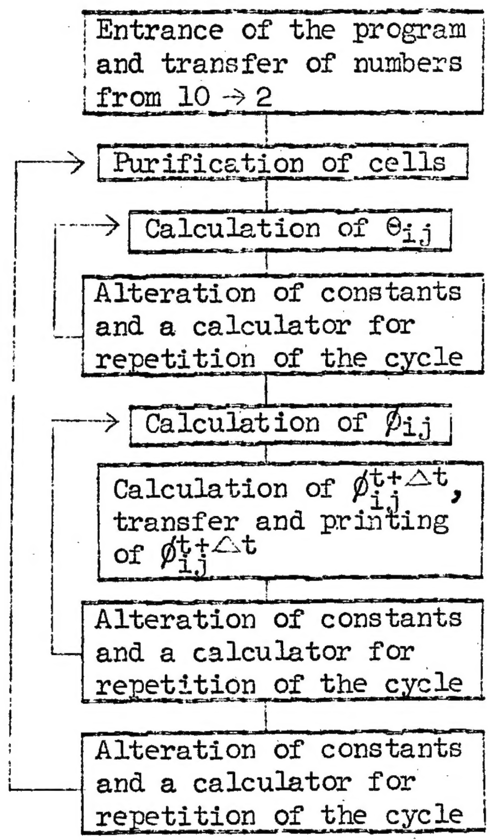
FIGURE APPENDIX



Block diagram of the program.

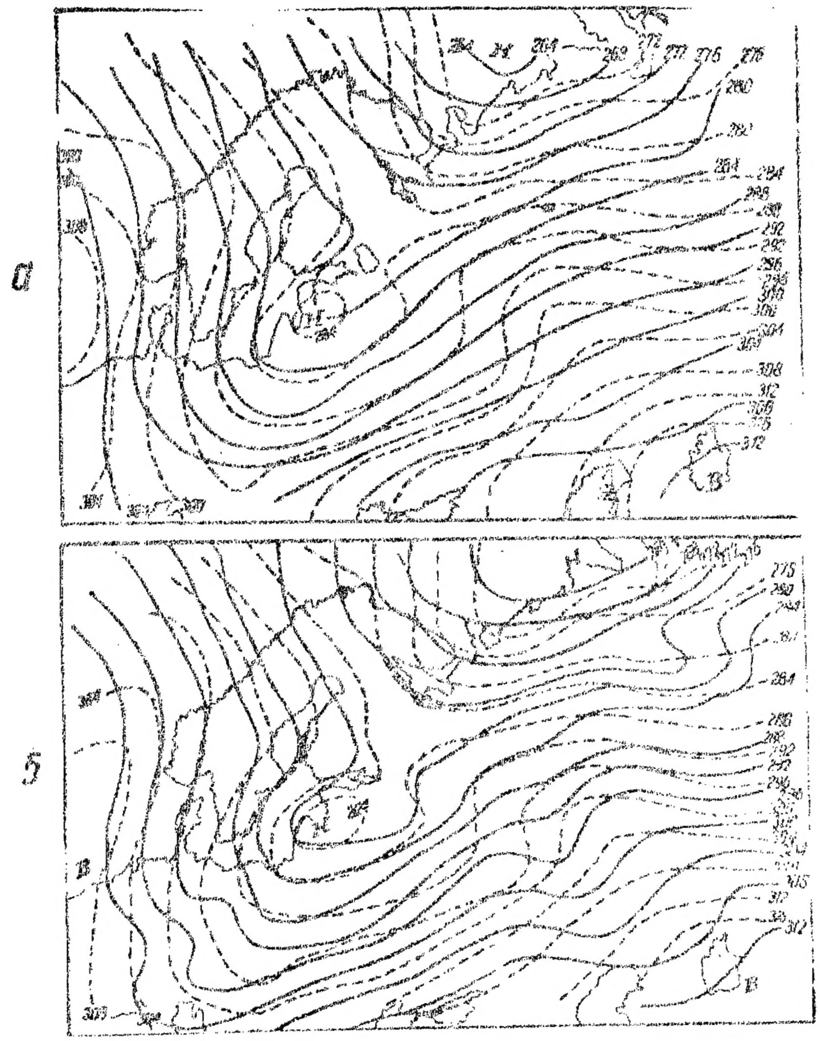


Figure 1a, b. AT-700 for 18 hours, 15 November 1954, calculated (solid lines) and actual (broken lines): a -- Δs = 500 km, Δt = 1 hour; b -- Δs = 500 km, Δt = 1.5 hours.

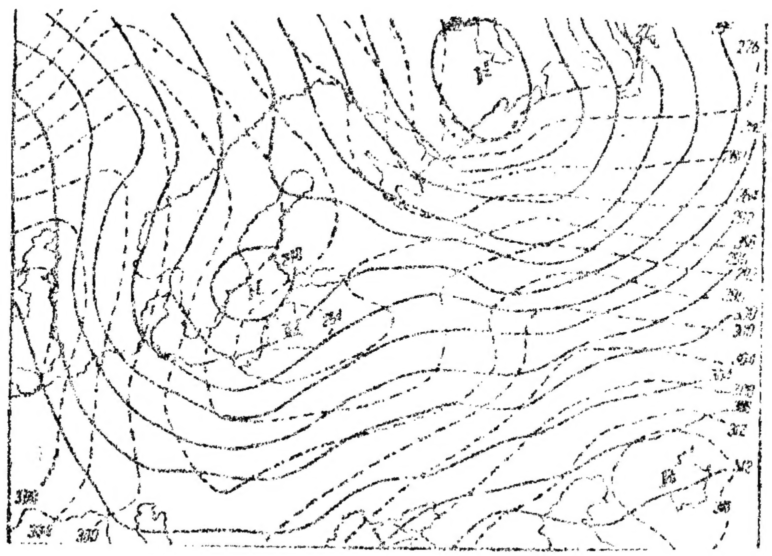


Figure 1c. AT-700 for 18 hours, 15 November 1954, calculated (solid lines) and actual (broken lines): $\Delta s = 200$ km, $\Delta t = 1$ hour.

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